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Introducing 'facilitymetrics': A first review and analysis of commonly used measures of scientific leadership among synchrotron radiation facilities worldwide

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Abstract
Big Science accelerator complexes are no longer mere tools for nuclear and particle physics, but modern-day experimental resources for a wide range of natural sciences and often named instrumental to scientific and technological development for innovation and economic growth. Facilities compete on a global market to attract the best users and facilitate the best science, and advertise the achievement of their users as markers of quality and productivity. Thus a need has risen for (quantitative) quality assessment of science on the level of *facilities*. In this article, we examine some quantitative performance measurements frequently used by facilities to display quality: technical reliability, competition for access, and publication records. We report data from the world's three largest synchrotron radiation facilities from the years 2004-2010, and discuss their meaning and significance by placing them in proper context. While we argue that quality is not possible to completely capture in these quantitative metrics, we acknowledge their apparent importance and, hence, we introduce and propose *facilitymetrics* as a new feature of the study of modern big science, and as a new empirical focus for scientometrical study, in the hope that future studies can contribute to a deeper, much-needed analysis of the topic.

Key words
Big Science; synchrotron radiation facilities; quality assessment; performance assessment; productivity

1. Introduction

Despite the relative decline of nuclear and particle physics after the end of the Cold War, Big Science is still a ubiquitous feature of governmentally sponsored science across the (western) world. The arms race and nuclear threat/promise logic of the technoscientific regime of the Cold War justified spending of billions of dollars on e.g. particle smashing accelerator complexes. Today, Big Science rather serves materials science (incl. nanoscience/-technology), life science, information science, and the overarching aim of promoting innovation for economic growth (Jacob and Hallonsten 2012; Elzinga 2012). Consequently, a dominant use of particle accelerators is nowadays the production of x-rays and neutrons for myriads of different and simultaneously executed experiments by academic and industrial users across a wide variety of fields. Accelerator-based *synchrotron radiation x-ray sources* used in this fashion for at least four decades have recently been complemented by accelerator-based so-called *free electron lasers* and *spallation neutron sources* (e.g. Westfall 2008, 2010, 2012; Hallonsten 2012). Globalization and internationalization of science, in tandem with technical advancements, has created a global market where facilities providing these experimental resources compete for the best users and, by extension, the most prestigious publication records.

In this article, we make a first attempt to conceptualize and examine the means by which modern Big Science facilities compete, that is, the metrics they normally use for benchmarking and to underpin claims of scientific quality. We use three cases from the large group of synchrotron radiation facilities globally, namely the three largest (in volume) and also those widely accepted as the world's leading three: the European Synchrotron Radiation Facility (ESRF) in Grenoble, France; the Advanced Photon Source (APS) at Argonne National Laboratory in Illinois, United States; and the Super Photon Ring 8 GeV (SPring-8) in Harima, Japan. We examine three basic measures of performance commonly used – technical reliability, competition for access, and publication records – and weigh them against basic data on funding, staff, and numbers of users. We have comprehensive data for seven years (2004-2010), obtained from annual reports, publication databases and, in some cases, directly from the communications offices/user offices at the facilities.[1] Variations in counting (most manifestly of course the mixture of calendar year and fiscal year, but also in other respects, see below) preclude or inhibit direct comparison. The aim, however, is not such direct comparison of performance, but rather to use the three cases to display differences and similarities in the data that can be explained by qualitative differences and similarities between the facilities. Hence, our aim is to *contextualize* the performance parameters and their use, and on basis of this we propose a (partly) new and increasingly relevant form of scientometrics, which we call *facilitymetrics*. The intended contribution is to introduce this topic, take a first crucial step in its analysis, and call for further and deeper studies. As part of this, we convey as a main point of this article the conclusion that scientific success of a facility, and the ability for a facility to claim a leadership position, stems from the ability to combine technical, scientific, administrative and social resources in the most user-friendly way.

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1. Annual reports are found at: http://www.esrf.eu/UsersAndScience/Publications/Highlights (ESRF), http://www.aps.anl.gov/Science/Reports/ (APS), and http://www.spring8.or.jp/en/news_publications/publications/research_frontiers/ (Spring-8). Publication databases are found at http://vmis2.esrf.fr:9090/flora_illesrf/servlet/LoginServlet (ESRF), https://beam.aps.anl.gov/pls/apsweb/pub_v2_0006.review_start_page (APS), https://user.spring8.or.jp/uisearch/publication (Spring-8). Some data for the APS is unavailable in the APS annual reports and was retrieved by personal communication.

The article begins with a brief basic orientation of synchrotron radiation facilities and presentations of the three cases. Thereafter, we introduce the three measures, and provide a basic interpretation of their meaning and significance. We conclude with a discussion on the findings and their implications, and concrete suggestions for future research.

2. Synchrotron radiation facilities

The closing of nuclear and particle physics accelerator centers across the globe, taking full speed in the 1990s and on, has not meant the end of the era of Big Science. Quite the opposite, large accelerator facilities have found new purposes in the growing areas of experimental materials science and life science (Westfall 2008, 2010, 2012; Doing 2009). The broad experimental opportunities opened by these facilities, and their potential proximity to technological innovation and hi-tech entrepreneurship, have brought renewed political interest in Big Science. The simultaneous development of a global market for state-of-the-art experimental facilities in materials and life sciences has made large scientific facilities the focus for both national and supranational science policy planning (Hallonsten and Heinze 2012; Hallonsten 2012, 2009; Krige 2003; Papon 2004).

We focus here on the world's three largest *synchrotron radiation facilities*. These are accelerator based research facilities where groups of researchers in a broad range of the natural sciences[2] make use of extremely intense radiation, foremost in the ultraviolet and x-rays range, for various experimental studies of matter. The utilization of synchrotron radiation produced by accelerators began in the 1960s and 70s as peripheral activities at particle physics laboratories, and has since grown steadily and had a manifold increase in numbers of users and disciplines served. Over the decades, technologies of handling and using the radiation have been gradually but profoundly refined,[3] and synchrotron radiation is now a mainstream laboratory resource in several of the fields it supports, with purpose-built facilities in operation in several European, Asian and American countries (Hallonsten 2009: 83-100). Especially the 1990s breakthrough entry into x-ray crystallography for life sciences applications has made research with synchrotron radiation a regular feature of the high-profile findings reported in *Nature* and *Science* (Doing 2009: 110, 127-144).

A rough count of the number of synchrotron radiation user facilities in operation globally yields approximately 40 (Hallonsten 2009: 301-303). These vary widely in size, mission, catchment areas, ambitions, and breadth of the instruments operated. There are no two synchrotron radiation laboratories in the world that are alike, although all share a few fundamental features. The descriptions below concern mainly the three cases (which are unusually large in size and ambitious in their scope) but generally fit most synchrotron radiation facilities worldwide.

Despite its origins at particle physics laboratories and despite its utilization of the same basic infrastructure, i.e. accelerators, research with synchrotron radiation is radically different from particle physics. At synchrotron radiation laboratories, a large number of instrument setups – *beamlines* – run simultaneously and support vastly different experiments. At the three facilities under study in this article, the number of separate beamlines are 41, 51 and 65,

2. The most common utilizations are in solid state and condensed matter physics, chemistry and other materials-related sciences, whereby various spectroscopic methods are used; biology, biochemistry, medicine and other life sciences, using the radiation for crystallography and other diffraction studies. There are also a number of smaller areas of utility in environmental sciences, cultural studies and archaeometry (Hallonsten 2009: 91-96).
3. For example, it is commonly claimed that the continuity of various technological innovations have made possible a doubling of the peak intensity (highest achievable intensity) of the radiation every 24 months(!) (Frahm and Williams 2007).

respectively; which in principle means that these three facilities are able to support the simultaneous work of 41, 51 and 65 independent user groups. Almost exclusively, these are ordinary research groups from universities and other institutions who more or less frequently travel to the facilities to conduct experimental work with instruments significantly more advanced and valuable for their work than the equipment their home institutions normally possess. The work of these user groups collectively makes up the bulk of the scientific accomplishments at the facilities, and so laboratories always seek to attract the 'best' users and also take credit for scientific achievements made using the instruments they host. Users travel the world in search of the most optimum instrument setup for their experimental purposes, and the critical resource is *beamtime*, by which is meant time with access to an instrument at a facility. The competition for beamtime is generally very high, and hence the existence of a reliable and credible procedure for granting outside user groups access, i.e. an organized peer review system, is crucial (Hallonsten 2009: 102-107).

This formalized system is built around a number of field-specific *proposal review panels* or *review committees* (names vary) with internationally leading experts in concerned fields, who review and grade the proposals that are sent in by users, by classic peer review assessment. Beamtime proposals are similar to grant applications in that they describe a project and its participants, but proposals should also show the project's technical feasibility, i.e. that the project in question is a good and efficient use of beamtime at a specific instrument.[4] Laboratories publish very detailed information on specific instruments, on basis of which researchers plan their proposals. Instruments differ widely in popularity, and the *oversubscription rates* are usually good measures of the communities' general demand for a certain technology or experimental opportunity.

The scientific and technical diversity and variability, the transient character of synchrotron radiation facilities as experimental resources, and the desire to attract the best science and hence the best user groups, places heavy demands on facility organizations, technically and administratively. Large numbers of scientific, technical, and administrative personnel are employed to take care of the beamtime allocation process and to accommodate the users and their requests so as to achieve the best possible conditions for the use of the facility and its instruments. Synchrotron radiation facilities, especially the three used as cases here, are therefore enormously complex organizations, which reflected in the several hundred million Euro annual budgets of the facilities (see figure 1).

Besides the organizational complexity, synchrotron radiation facilities are also highly sophisticated machines. Running an accelerator 24 hours a day, 365 days a year at a certain level of performance requires technical and scientific stringency and strength. The quality of the radiation delivered to the users at the beamlines can be improved in several ways (by focusing and tuning) but is ultimately determined by the performance of the accelerator.[5] Not least, the *reliability* of the machine is of great important for the users. No synchrotron radiation facility can be operated without occasional breakdowns, but there are several ways to improve reliability, and the three facilities under study here are among those most successful

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4. Generally, proposals are judged only by their scientific quality and technical feasibility, but exceptions exist, for example the favoring of inexperienced applicants in order to make user communities less static, and attempts to achieve better gender equality (Hallonsten, 2009: 187).
5. The technical performance parameters shown in table 1 (energy, current, and emittance) are very straightforward measures of accelerator performance, i.e. a greater value normally means a better accelerator or a more capable synchrotron radiation facility. There are several other parameters determining accelerator performance, but these are severely more complicated to assess (Hallonsten 2009: 80-83).

in maximizing *beam availability*, i.e. the percentage of scheduled time actually delivered to users without interruption (see below) (Hallonsten 2009: 82-83).

Technical complexity and high cost may prevent comprehensive construction of fully equipped facilities at once, and it is not uncommon for scientific and technical expertise in some areas to be found among external research groups (future users) rather that within facility organizations. Therefore, teams or consortia of several teams have often been invited to design and construct instrumentation for use at the facility, whereby a kind of *buy-in* arrangement is made that normally gives the responsible group(s) the privilege of priority to the instrument, for example a specially allocated amount of time on the instrument each year (or scheduling period). This arrangement is common at the facilities under study (called Collaborating Research Groups, Collaborating Access Teams, and Contract Beamlines) (Hallonsten 2009: 102).

Like most institutions in modern non-proprietary science, synchrotron radiation facilities care a great deal about measuring and demonstrating their output, and like most, publication counts is the preferred metric. Since the users are ordinary scientific groups, the results of the work conducted at the facilities are communicated in ordinary journals (as well as books, conference papers, etc.). Naturally, a good publication record is considered an indication that a facility performs well as user facility in the science system (Hallonsten 2009: 104). The three facilities under study here keep meticulous track of publications[6] and have open publication databases online (from which some data for this article have been retrieved), as well as summaries of publication statistics in their Annual Reports, where they are used to mark of productivity and quality.

3. The cases

The three cases under study here, the ESRF, the APS and the SPring-8, are the world's three largest synchrotron radiation facilities, counting physical size of the labs, annual number of users, annual operation budgets, and outputs (publications). These three facilities were conceived, designed and built almost simultaneously, in the late 1980s and early 1990s, and were the respective flagship facilities for materials science and life science in Europe, the United States, and Japan at their time of opening 15-20 years ago. Since then, they have been complemented in their respective countries/regions by other synchrotron radiation facilities, significantly smaller and designed for more specific needs. Therefore, they remain the world's largest but have lost the lead in several specific experimental areas to other facilities elsewhere. Their breadth and generally high performance, however, remain unmatched.

The ESRF is a joint European laboratory located in Grenoble, France and collectively owned by 17 member countries, built on a multilateral agreement that establishes the facility as a French private company (*société civile*) owned by the organizations through which the countries are members. The ESRF operates on a budget of annual contributions from the member organizations, decided in advance and corresponding to their shares in the company. The origins of the ESRF date back to the experience of the comparably successful creation of a number of European intergovernmental collaborative projects in science in the 1950s and on,[7] and the 1977 proposal by the European Science Foundation (ESF) that a collaborative European synchrotron radiation source be built to satisfy European scientists' future demands

6. Normally, it is required of users that they report publications based on previous beamtime to facilities in order to be awarded new time on their proposals.

7. For example, the European Organization for Nuclear Physics (CERN), the Joint Research Centre (JRC) for nuclear physics, the European Southern Observatory (ESO) and the European Space Research Organization (ESRO) (Krige 2003: 899).

of high quality synchrotron radiation. Efforts to mobilize a community and specify the desired performance parameters of the new facility soon resulted in the formulation of high-level ambitions; the ESRF would be as *complete* a synchrotron radiation laboratory as possible, offering both breadth (satisfied by size, i.e. a large accelerator with a large number of independent experimental stations) and, perhaps most importantly, unprecedented scientific opportunities facilitated by a technical design that would allow a performance greatly surpassing existing European facilities with great margin. This bold ambition is said to have been decisive in the process of mobilizing political support for the project among the European governments that would eventually fund it (Hallonsten 2009: 229). Nonetheless, politics delayed the project several years. The complicated site-selection process, in which nearly every prospective member country put forward their own candidate site, was only resolved by a behind-the-doors agreement between France and Germany to fund a majority of the construction budget and locate the facility to Grenoble.[8] Other countries joined the agreement,[9] and in January 1989, construction work on site in Grenoble began. The first preliminary experiments started in 1993, and in 1994, the facility opened to users. An important detail, often mentioned as a major reason for the continuously strong performance of the ESRF on several parameters (see next section), is that the founding documents stipulated that new investments and refurbishments of instruments should be an annual budget post, using 20% of the annual operations cost. This has allowed the facility to maintain a rather aggressive refurbishment and maintenance program, and the fact that it is laid down in the founding documents of the facility has kept this specific budget post intact. 10 of the 41 beamlines operated at ESRF are run by so called Collaborating Research Groups (CRGs) who are organizationally entirely separate from the ESRF and entitled to use of 2/3 of scheduled beamtime for its own purposes, making the other 1/3 of the time available to the general beamtime allocation process (Hallonsten 2009: 207-238).

The APS is a federal U.S. synchrotron radiation facility located at the Argonne National Laboratory in Illinois and funded by the United States Department of Energy. Similarly to the ESRF, the APS emerged as a concept in the 1970s due to predictions of a multiplying demand among US scientists for synchrotron radiation, but it was also the product of particular institutional and political circumstances. The United States National Laboratories system, founded in the aftermath of World War II to run the nuclear energy R&D program both for military and civilian purposes, had started to experience disarrays due to the concentration of resources for high energy physics at a smaller number of labs. Both Lawrence Berkeley National Laboratory and Argonne were essentially without a core mission after their high energy physics machines had been dismantled, and needed infrastructural as well as scientific renewal in order to motivate their continuous existence. Money was, however, flooding the growing area of materials science, and synchrotron radiation was a resource of growing importance in this field (Westfall 2012: 441). Technical advancements along the lines of those made in the development of the ESRF case, as described above, led to the proposal of a similar

8. This agreement should be properly placed in the broader context of the early-1980s renewed Franco-German collaboration on European level that produced the Framework Programmes, the Single European Act of 1985, and eventually, the Maastricht Treaty and the Euro currency (Hallonsten 2012).

9. The shares were, eventually, distributed as follows: France (33% of the construction costs; 27.5% of the operations costs), the Federal Republic of Germany (23%; 25.5%), Italy (14%; 15%), United Kingdom (12%; 14%), the Benesync consortium comprising of Belgium and the Netherlands (6%; 6%), Spain (4%; 4%), the Nordsync consortium comprising of Denmark, Finland, Norway and Sweden (4%; 4%), and Switzerland (4%; 4%). The French contribution to the construction budget also included the site in Grenoble, ready to build on, free of charge (Hallonsten 2009: 218).

big facility that would provide both breadth and unprecedented experimental opportunities. Argonne soon emerged as the logical choice of site for the new facility, given the lab's need of a new major mission, and the lab organization started proactive work to define the future facility scientifically and technically as well as building a scientific user base, partly in collaboration with the ESRF team in Grenoble. Construction of the facility began in 1989, and it opened to users in 1995 (Westfall 2012: 443-448). Despite being the largest piece of scientific infrastructure in the National Lab system at its opening, a cap on DOE spending put in place as part of an effort to reduce the federal budget deficit in the early 1990s caused severe underfunding of the whole facility (Westfall 2012: 448). The funding granted in 1991 for APS construction did not include a complete set of beamlines and experimental stations, which meant that most of the beamlines had to be outsourced to external groups forming what at the APS is called Collaborative Access Teams (CATs) (Holl 1997: 472-473). While ensuring the enrollment of crucial expertise for the design, construction and operation of experimental stations, this extensive reliance on CATs not only for construction and maintenance of beamlines, but also operation and user support, led to insufficient coordination and cooperation between the units and ineffectiveness in technical maintenance and user operation (Hallonsten 2009: 129-130). The contrast to ESRF is significant: There, the facility was funded in its entirety with 30 complete beamlines including all instrumentation and the hiring of adequate staff, and money earmarked for continuous development and improvement. At the APS, a similar comprehensive and coordinated funding profile and organization has only recently been achieved by organizational overhaul and long needed budget increases (Hallonsten 2009: 234).

The SPring-8 is by far the world's (physically) largest synchrotron radiation source (see table 1), located in the Harima Science Garden City, approximately 100 km northwest of Osaka, Japan. Research activities utilizing synchrotron radiation had had a similar development in Japan as in Europe and the United States in the 1960s and 70s, and by the early- to mid-1980s, plans of a new big facility were being drafted. The effort was national – user groups and existing facilities from all over Japan got together to plan and design the new facility, and with the strong support of the local government of Harima, the Spring-8 took shape in the early 1990s (Sasaki 1997: 364). The facility opened to users in 1997, and was initially under the supervision of the Japan Atomic Energy Research Institute (JAERI). In 2005, the JAERI withdrew from management of Spring-8 and was replaced by the Japan Synchrotron Radiation Research Institute (JASRI) and RIKEN (Japanese abbreviation for *Rikagaku Kenkyūjo*, which translates to the Institute of Physical and Chemical Research), who jointly run the facility (Spring-8 2012). While technically and scientifically very similar to the APS and the ESRF, the Spring-8 differs from these in two important respects. First, by its size, which has marginal implications for technical and scientific performance but which makes possible a larger number of beamlines (see table 1). Second, direct involvement by industry at the Spring-8 is significantly larger than the Europe and US counterparts. This is seen both in the number of contract beamlines (i.e. beamlines owned by a third party, usually and industrial firm), and in the estimated amount of beamtime used for proprietary research annually, which at Spring-8 is 25%, compared to between 5% and 10% for ESRF and APS (NUFO 2009: 7).

Before we proceed to present and analyze data, a methodological note is necessary. Unfortunately, in the sources for the data, namely official reports from the facilities, there is no consistency with regard to the use of fiscal year (FY) and calendar year (CY). In the appendix table as well as in the diagrams, data is clearly marked with FY and CY to indicate which is the case. In the figures below, similar marking is also provided as clearly as possible.

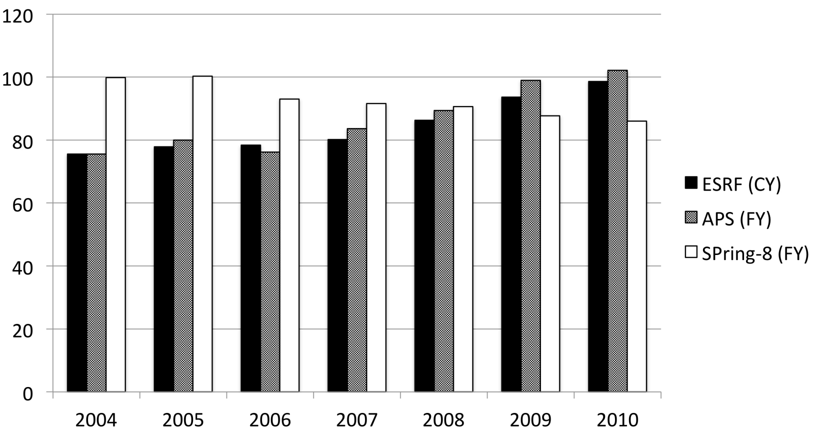
If the purpose here would be direct comparison between the cases, this unfortunate mixture would naturally present a major obstacle or even thwart the whole effort. Nonetheless, we maintain that these figures are valid for the purposes in this article: Its main ambition is to *analyze and discuss* data, what they *represent*, and *what this means in a broader perspective*, and not to present them as finalized (and directly comparable) measures of, e.g., performance.

Table 1: basic parameters of the three cases (2010)

	ESRF	*APS*	*Spring-8*
Energy (GeV)	6.03	7	8
Maximum current (mA)	200	100	100
Horizontal emittance (nm)	4	2,5	3,4
Vertical emittance (nm)	0,005	0,04	0,0068
Circumference (m)	844	1104	1436
Opened to users	1994	1996	1997
Number of beamlines	41	31	51
Of which are buy-in beamlines	10	14	25

Table 1 and figures 1, 2 and 3 provide some basic information about the three cases. While the annual budgets are similar (figure 1), we can conclude that SPring-8 also in a non-physical sense is the largest among the three facilities with significantly larger numbers of users and staff than the two others. It is, of course, intriguing to see that SPring-8 appears to be able to run a significantly larger laboratory with significantly larger numbers of users than the two others, on a similar budget level. Several explanations are possible, for example related to national differences as well as differences in laboratory organizations, but we will save these for later and instead proceed to the other data.

Figure 1: Total annual budgets, 2004-2010 (M€)



4. Facilitymetrics

The first of the three main areas of performance measurement of the facilities is *technical reliability*, which from the users perspective translates to *availability*, i.e. percentage of scheduled operation actually delivered without shutdowns. Figure 4 shows primarily two things. First, that reliability is generally quite high, oscillating between roughly 98% and 99%, which corresponds roughly to between 50 and 100 hours unwantedly not delivered to users in a year. Second, the graph shows that reliability varies greatly within this generally high interval, which we take as an indication that once generally high levels of reliability are reached, comparably smaller variation is probably inevitable.

Figure 2: Total number of staff (yearly FTE), 2004-2010

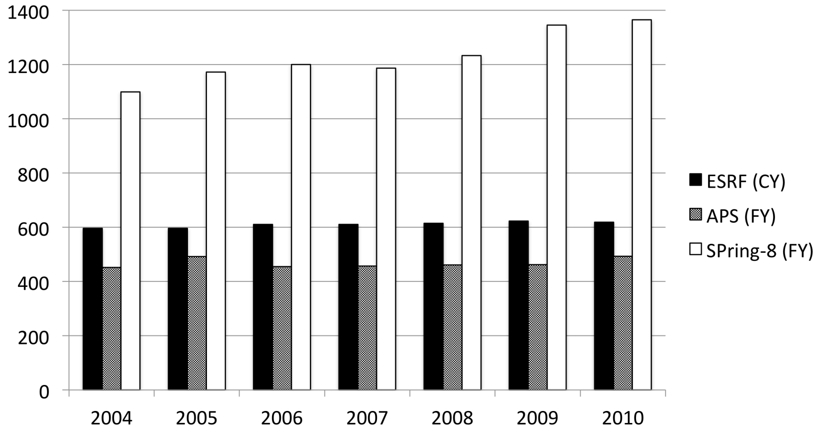


Figure 3: Total annual number of users, 2004-2010

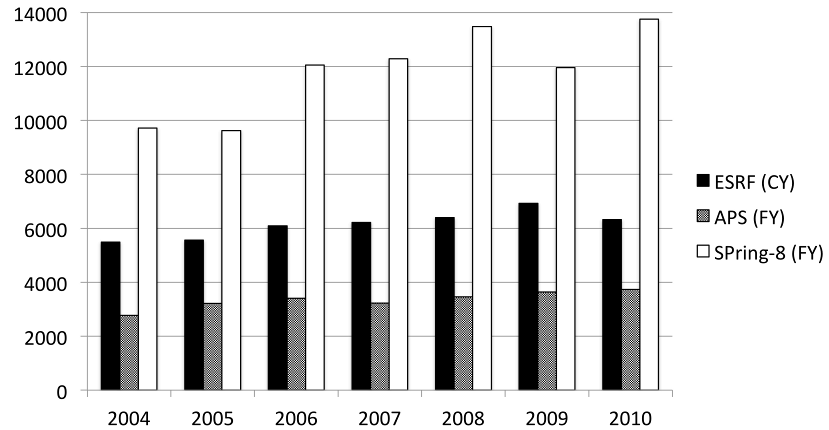
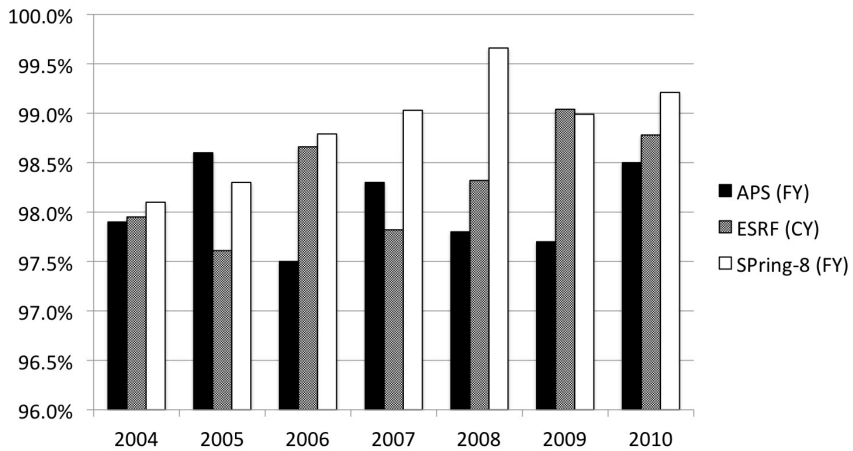
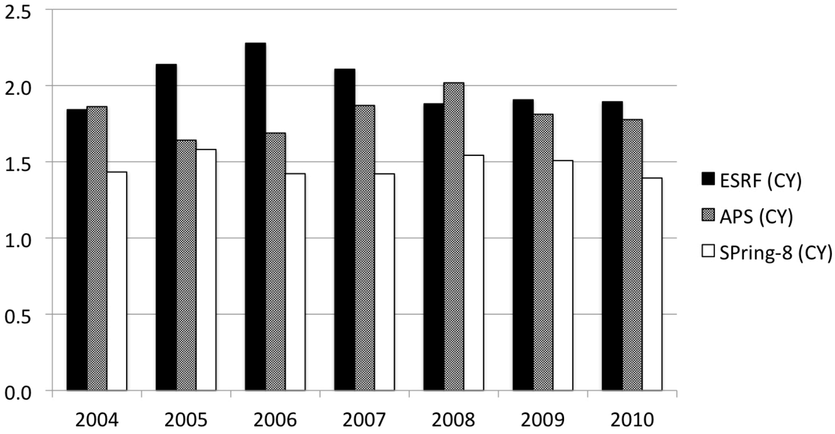


Figure 4: Availability, 2004-2010



Turning now to the perhaps most dynamic measure of quality or performance of a facility, namely oversubscription rates, we start with some remarks on the nature of this measure. First, it shall be noted that the data displayed in figure 5 is on the most overview level, since they describe overall oversubscription rates for the whole facilities.[10] Given the large number of parallel instruments operated and disciplinary areas served at the labs, similar data on another level of detail would most likely yield great variations. Second, it must be noted that there is a slight variation in how these rates are calculated, but given the ambition here and the overview level of analysis, this is a minor issue. It can be noted that the significantly larger overall number of users at SPring-8 compared to the other two cases (see figure 3) is a likely contributing explanation for the relatively somewhat lower oversubscription rate for SPring-8 shown in figure 5 – a larger capacity reasonably lowers competition.

Figure 5: Oversubscription rates, 2004-2010



To go into deeper and contextualized analysis, we may note that oversubscription rates have part of their origin in the internal (and sometimes informal) ranking systems of science whereby a scientific community keeps track of the most valuable or prestigious technical resources available. These internal rankings are as important as they are difficult to grasp for the outsider – a myriad of factors are usually weighed in, apart from technical performance and reliability can be mentioned the skills of the technical support personnel and safety rules that restrict the use of certain samples or modifications on the instruments. A high oversubscription rate is likely to correspond to a greater amount of prestige and recognition among peers awarded to the scientist that manages to get access. It is also directly connected to the logics and workings of peer review, given the nature of the beamtime allocation procedures, which makes it the most classic scientific performance measure among the three under consideration here.

The third of the measures analyzed is the perhaps most typical and generalizable among the three. Measuring publication output on macro-level is both a growingly popular tool for science policy and management and a highly contested method to measure and display performance or quality.

But obviously, for these measures to make real sense, they have to be weighed against other characteristics such as size of the units measured, variety in publication behavior within the units, type of publications (different journal types), etc. Here, most obviously, we should take into account the variety in size of the three facilities, more specifically the number of beamlines (i.e. individual experimental facilities) and the number of users, complementary indications of the relative research *capacity* of a facility. The disciplinary spectra covered by

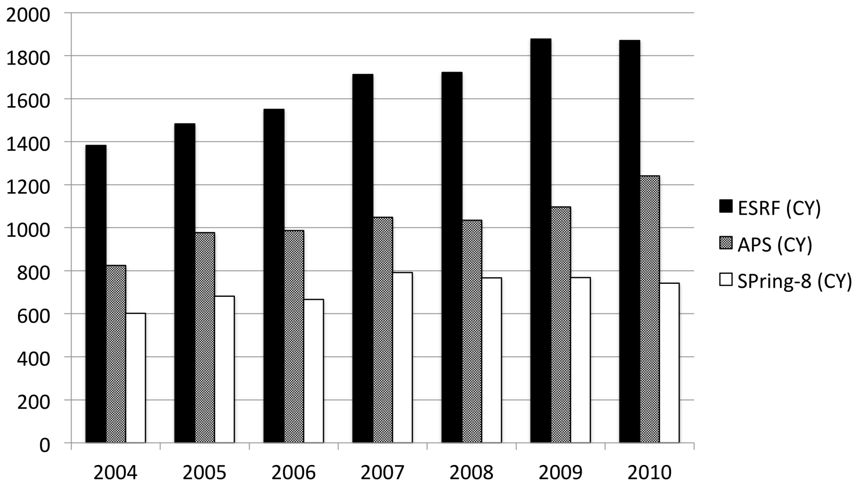
10. This is calculated by dividing proposal request with actual allocation. Exact measures vary somewhat (see appendix table); for the ESRF and APS the diagram shows an average of two measures (time requested/allocated, and number of proposals submitted/accepted). For SPring-8, only one measure is available, namely number of proposals submitted/accepted, and this value is hence represented directly in the diagram.

the three facilities are roughly the same, but internal variations are highly probable, e.g. the relative dominance of different fields at different facilities, and this can quite naturally also be a factor behind variations in overall publications measures.

Interestingly, the ESRF has the smallest number of beamlines and not the largest number of users (see table 1 and figure 3), but outperform the two other facilities greatly in terms of number of publications. In comparison with the APS, the difference in number of publications seems to be roughly the same as both the difference in number of users and number of staff, which makes the difference reasonable and natural, if one ignores the difference in number of beamlines, which indeed is quite large but might be explained by the greater number of buy-in beamlines at APS.[11] The comparison with SPring-8 is, however, significantly more puzzling and will be returned to below.

Though the measure is very broad and lacks much of the detail that would be necessary to make stringent comparison, the discrepancies could be used as an argument by ESRF representatives that their facility is significantly more efficient than the two other, a claim that likely has some factual basis.[12]

Figure 6: Total annual number of journal publications, 2004-2010



Turning now to the curious case of SPring-8, we may only speculate why this facility – despite its size and its number of users, the latter of which approach double that of ESRF and triple

11. This explanation for the apparent performance lead of ESRF is reported by Hallonsten (2009: 234-235) in his comprehensive study of the facility. Though only representing the ESRF perspective on the matter, the study displays what seems to be a crucial difference between the APS and the ESRF in organizational structure, that appears to have an impact on scientific performance. While the ESRF management has always had a deliberate strategy to facilitate high-quality work by external users, a strategy sustained by the generous budget of the lab regulated in the founding documents, the APS was built up with heavy reliance on buy-in arrangements under the name Collaborating Access Teams (CATs). These arrangements secured vital scientific and technical competences in building up the lab but also incorporated organizational compartmentalization and insufficient coordination between units, which eventually led to ineffectiveness in technical maintenance and user operation (Hallnsten 2009: 130), a matter also recognized in a 1997 national review of US synchrotron radiation facilities (Birgeneau and Shen 1997: 101).

12. In fact, the clear lead of ESRF among the three is something that ESRF management takes every opportunity to advertise. The then-ESRF director-general is quoted in Hallonsten (2009: 234) saying: “For every two publications produced by the APS, the ESRF community produces three. We produce between 2 and 3 times as many publications as SPring-8. The budgets are broadly comparable. [...] These publications, our different libraries have looked at them together, so we all agree that they correspond to the same thing. It’s not measuring elephants on one side and zebras on the other. So as far as we can tell, that is a fair thing.”

that of the APS – does not have as impressive a publication output as the other two. Significantly less background information is available on this case compared to the other two, which are well documented in historical and sociological works (Hallonsten 2009; Holl 1997; Westfall 2012). A rough calculation, not carried out fully here due to the aforementioned mixture of CY and FY in the two data sets, yields that while each journal publication at the ESRF and APS requires an average of 3-4 registered users, at SPring-8 each journal publication requires over 14 and occasionally 18 users. Part of the explanation could be the relatively large share of proprietary work facilitated by SPring-8, estimated to 25% of all beamtime, as this use of beamtime by nature is normally not published. The whole gap between the SPring-8 and the two others in average number of users per journal publication can, however, not be attributed to this fact. Further explanations – we may only speculate about things like national differences in research cultures – will have to be sought in future studies.

5. Discussion and conclusions

The various measures presented and briefly discussed in the last section are commonly used by facility managers and among users as more or less informal indicators of quality, performance, and by extension, world leadership. As a scientometric subfield, however, these measures are novel and their analysis only in its infancy, and the discussion above and below is hence tentative and probing by nature. Hence, unavoidably, several question marks surround both the figures and the discussion around their interpretation.

Leaving aside the purely methodological issues (as discussed above: the mix of calendar years and fiscal years, and the question of generalizability), the most pressing issue is, quite naturally, how performance of modern big science facilities could or should be measured, and for whom such performance measurement has impact or relevance. The simplified and straightforward answer to this is something like the following. For the user, reliability and beam availability is one relevant measure. Other things in the users immediate surrounding, likely just as important but impossible to visualize in pure numbers and figures, are quality of user support, reliability of other instruments in the lab including sample handling and data processing. These may of course be partly represented by, e.g., oversubscription rates that show the popularity of facilities and instruments, but not directly measured by other means than qualitative case studies. Thus the first weakness of the ambition to measure performance and quality by pure numbers is unveiled by invoking the seemingly trivial realization that numbers cannot account for everything – "Everything that counts cannot be counted, and everything that can be counted does not count" as Albert Einstein purportedly said.

The validity of oversubscription rates as measure of performance of quality is also debatable. On the one hand, on a (global) and open market, competition and degrees of competition is a natural measure of relative quality, expressing clearly the ratio between supply and demand. On the other hand, oversubscription rates may also give false impressions – in the case of ESRF, it has been brought up that extremely high competition may cause 'asymptotic behavior' in the user community, by which is meant that oversubscription rates suddenly drops after years of high levels, due to users giving up and submitting their proposals elsewhere (Hallonsten, 2009: 267-268). This would indicate that there is limited use of oversubscription rates for settling on impressions of quality of different facilities in the user communities. For funders, policymakers and lab administrators, however, it might be a rough but fairly adequate indication of the quality of a facility as expressed by demand in the scientific community.

Publication counts have well-documented advantages and disadvantages. Fundamentally, quantity is of course an inadequate measure of quality. Given the current (and growing) status of publication track records as a measure of quality or excellence of scientists and institutions, however, one cannot dismiss them entirely. In the case of large and costly scientific infrastructures, it might indeed be relevant to compare publication volume with, numbers of users, facility operations budget, and perhaps scientific support staff, in order to achieve a rough measure of efficiency and productivity of publicly funded, expensive, research installments. Quite obviously, though, such comparison must be made with nuanced contextualization of the numbers along the lines of the brief historical notes in a previous section, and not least with numbers that allow direct comparison.

Partly on basis of this discussion, it is reasonable to present as the main conclusion of this paper that scientific success of a facility in reality depends on a wide variety of technical, scientific and organizational factors. A combination of high performance on all or several of these is likely required for an overall high scientific performance of a synchrotron radiation facility. By extension, it is quite tempting to introduce causal relationships between the factors. For example, high machine reliability and hence availability can create a higher demand and thus increased competition, something that easily translates to a good reputation among both users and prospective staff and makes the facility increasingly attractive for talented scientific and technical staff and prominent experiments. The presence of these at the facility may improve publication records as well as the quality of user support, and so on.[13]

But the complexity of the scientific 'quality' and 'excellence' labels is, of course, nothing new. Having established in this article that this complexity goes beyond the easily measurable also for large scientific user facilities is indeed little more than the repetition of a well-known caveat in a partly new setting. Why, then, should all this render any attention? First, as mentioned in the introduction, there is a policy-driven increase in interest in research infrastructures and specifically big science facilities as sources of innovation and economic development, which warrants and calls for an assessment of various ways of measuring performance of these facilities. In this article, whose limitations and preliminary nature have been fully acknowledged, we have displayed the potential of 'facilitymetrics' and highlighted some basic preconditions for such studies. Bu this, we hope to have inspired deeper and more comprehensive analyses of this topic that can hopefully, eventually, also lead to the devising of a more robust and reliable metric and system for the assessment of quality markers for modern big science.

But there are also broader implications that might have some interest in the sociology of science. For example, one might well compare the competitive element in the granting of access to these facilities with other competitive processes in the social system of science, e.g. grant application procedures and publications. Just as a grant is necessary for conducting research and the publication of results in acknowledged journals is crucial for the sustaining of a career in science, access to high-quality beamtime is vital for the conduct of some experimental studies. The wide (and growing) use of synchrotron radiation across the disciplinary spectrum as well as the steep growth in number of users over the past decades is a testimony to the growing importance of beamtime as a resource in several natural science disciplines. This article has merely scratched the surface, but by doing so arguably put the spotlight on yet another instance in science where performance measurement is established practice, and where the metrics used are suffering from a myriad of obfuscating features

13. Cf. the concept of *cumulative advantage* proposed by Merton (1968) for the accumulation of credit in science.

whose analysis can become a vital contribution both to scientometrics and to the study of modern large scientific user facilities.

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Appendix table: Data

	2004	2005	2006	2007	2008	2009	2010
							Total annual budget. converted to €.
ESRF (CY)	75546000	77827800	78360200	80203400	86304600	93650300	98647700
APS (FY)	75548360	79998000	76132624	83580000	89382840	98942800	102126800
SPring-8 (FY)	99852052	100317846	93027158	91619650	90647558	87731283	85989618
							Total annual FTE staff
ESRF (CY)	596	596	610	611	615	623	618
APS (FY)	452	492	455	457	461	462	493
SPring-8 (FY)	1099	1172	1200	1186	1233	1345	1365
							Total annual number of users
ESRF (CY)	5488	5565	6092	6222	6395	6927	6318
APS (CY)	2769	3217	3410	3229	3462	3642	3729
SPring-8 (CY)	9717	9626	12051	12281	13483	11956	13749
							Total annual number of journal publications
ESRF (CY)	1383	1483	1550	1713	1722	1877	1871
APS (CY)	824	977	987	1049	1035	1097	1241
Spring-8 (CY)	602	682	667	792	767	768	742
							Machine availability figures
ESRF* (CY)	97.95%	97.61%	98.66%	97.82%	98.32%	99.04%	98.78%
APS* (FY)	97.90%	98.60%	97.50%	98.30%	97.80%	97.70%	98.50%
SPring-8** (FY)	98.10%	98.30%	98.79%	99.03%	99.66%	98.99%	99.21%
							Figures for SPring-8
Hours of planned user time (FY)	4680	3762	3816	4008	4125	4056	4104
Hours of achieved user time (FY)	4590.9	3698.2	3770	3969.3	4110.9	4014.9	4071.6
							Oversubscription rates ESRF (CY)
Shifts requested	3203	3894	3421	2918	3104	3583	3242
Shifts allocated	1309	1351	1036	981	1257	1362	1306
Oversubscription rate 1	*2.45*	*2.88*	*3.30*	*2.97*	*2.47*	*2.63*	*2.48*
Proposals submitted	1675	1881	1892	1907	2013	2047	2035
Experimental sessions	1355	1349	1510	1539	1559	1731	1559
Oversubscription rate 2	*1.24*	*1.39*	*1.25*	*1.24*	*1.29*	*1.18*	*1.31*
Mean oversubscription rate	1.84	2.14	2.28	2.11	1.88	1.91	1.89

							Oversubscription rates APS (CY)
Beamtime requests	1717	1767	2101	2249	2898	3081	3347
Beamtime slots allocated	991	1112	1299	1276	1525	1795	2015
Oversubscription rate 1	*1.73*	*1.59*	*1.62*	*1.76*	*1.90*	*1.72*	*1.66*
Proposals submitted	1079	1139	1406	1336	1538	1613	1671
Allocated proposals	542	672	799	676	720	846	883
Oversubscription rate 2	*1.99*	*1.69*	*1.76*	*1.98*	*2.14*	*1.91*	*1.89*
Mean oversubscription rate	1.86	1.64	1.69	1.87	2.02	1.81	1.78
							Oversubscription rates Spring-8 (CY)
Proposals submitted	1658	1851	1783	2106	2172	2055	1941
Proposals accepted	1157	1171	1254	1482	1408	1363	1393
Oversubscription rate	1.43	1.58	1.42	1.42	1.54	1.51	1.39

* These are reported directly by the facilities and hence taken here at face value.
** These are calculated on basis of figures of planned and achieved user time (in hours) reported by the facility.

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